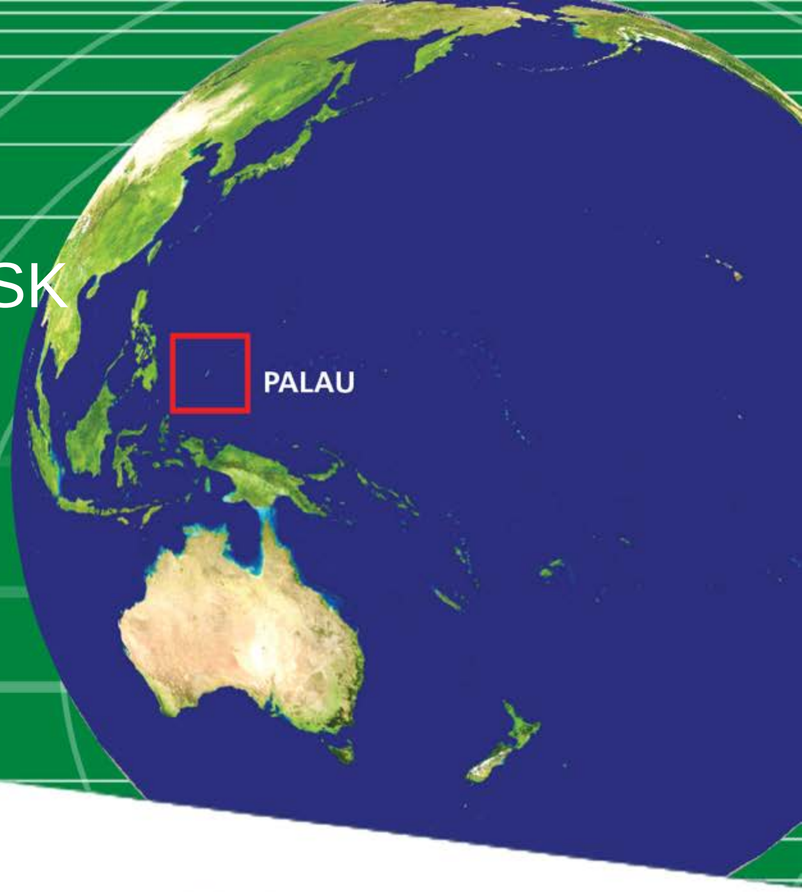
CURRENT AND FUTURE TROPICAL CYCLONE RISK IN THE SOUTH PACIFIC



COUNTRY RISK PROFILE: PALAU

JUNE 2013

- *Palau has been affected by devastating cyclones on multiple occasions, e.g.1976 tropical cyclone Marie, 2001 tropical cyclone Utor. The current climate average annual loss due to tropical cyclones represents about 1.4% of the country's GDP.*
- *End-of-century projections generally indicate a decrease in losses from tropical cyclones compared to the current climate. However, larger increases in losses are projected for more extreme events (> 175 year return period).*
- *Losses from 1-in-250 year tropical cyclones could increase by as much as 21.9% in the worst case climate change scenario.*
- *By end-of-century, the proportion of the population affected by tropical cyclones is projected to decrease compared to the current climate.*
- *Maximum wind speeds produced by tropical cyclones in Palau are expected to decrease slightly by end-of-century.*

Pacific Catastrophe Risk Assessment and Financing Initiative
in collaboration with
Pacific-Australia Climate Change Science and Adaptation Planning Program

Australian AID

BETTER RISK INFORMATION FOR SMARTER INVESTMENTS

PROJECT GOAL

Contributing to the third phase of the Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI), this project is supported by the Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) Program with co-financing from the Global Fund for Disaster Risk Reduction. The primary goal of the project is to improve understanding of the risks posed by tropical cyclone hazards (winds, floods, and storm surge) to key assets in the Pacific region, under current and future climate scenarios. A clearer understanding of the current level of risk in financial terms - and the way that risk will change in the future - will aid decision makers in prioritising adaptation measures for issues such as land-use zoning, urban infrastructure planning, and ex-ante disaster planning.

EXPOSURE AND POPULATION

The building assets considered in this study include residential, commercial, public and industrial buildings, while the infrastructure assets include major ports, airports, power plants, bridges and roads. The major crops in Palau are cabbage, cucumber, watermelon, and cassava, among others.

Table 1: Summary of Population and Exposure in Palau (2010)

Total Population	20,500
GDP Per Capita (USD)	8,280
Total GDP (million USD)	169.7
Total Number of Buildings	5,719
Number of Residential Buildings	4,665
Number of Public Buildings	325
Number of Commercial, Industrial, Other Buildings	729
Hectares of Major Crops	3,622

As estimated and detailed in the previous phase of the project, the replacement value of all assets in Palau is 1.5 billion USD of which about 89% represents buildings and 11% represents infrastructure. This study did not take into account future economic or population growth. Table 1 includes a summary of the population and exposure in the islands.

AIR TROPICAL CYCLONE MODEL

AIR has developed a South Pacific catastrophe parametric model to evaluate the tropical cyclone risk for 15 countries in the region. Historical data was used to build a stochastic catalogue of more than 400,000 simulated tropical cyclones, grouped in 10,000 potential realisations of the following year's activity in the basin. The catalogue provides a long-term view of tropical cyclone activity in the region. It was built to physically and statistically reflect the most credible view of current risk based on the historical record including frequency, intensity and track evolution. The model estimates hazard (wind speeds and flooding levels) and damage (losses) for all events in the catalogue.

CURRENT CLIMATE

Palau is located north of the equator in an area known for the frequent occurrence of tropical cyclones with damaging winds, rains and storm surge. Palau has been affected by devastating tropical cyclones on multiple occasions during the past few decades. For example, in 1976 tropical cyclone Marie destroyed crops and damaged buildings and public utilities, and caused more than 4 million USD in damages that left Palau a major disaster area. More recently, tropical cyclone Utor in 2001 resulted in 4 million USD in damages.

The country's current tropical cyclone risk profile has been derived from an estimation of the direct losses to buildings, infrastructure and major crops, as caused by wind and flooding due to rain and storm surge. 'Losses' in this report refers to the direct costs needed to repair or replace damaged assets *plus* the emergency costs that governments may sustain as a result of providing necessary relief and recovery efforts (e.g. debris removal, setting up shelters for those made homeless, or supplying medicine and food).

The average expected losses per calendar year are referred to as the *Average Annual Loss* or *AAL* (see Appendix). The current climate AAL value is 2.3 million USD. The percentage distribution for the different assets considered is shown in Figure 1.

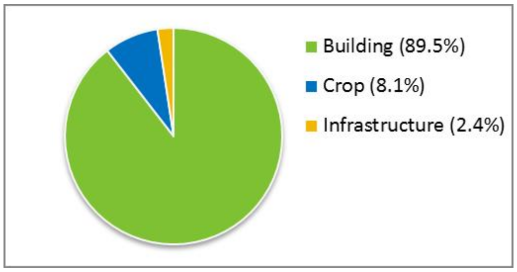


Figure 1: Contribution to total Average Annual Loss (AAL) from the three types of assets considered

The model also estimates losses from more infrequent tropical cyclones that are stronger and more damaging such as 50, 100 and 250 year return period (RP) events. The current losses from such events are: 13.2 million USD (50 year RP), 34.1 million USD (100 year RP) and 125.3 million USD (250 year RP), respectively.

FUTURE CLIMATE

As part of the project, Geoscience Australia (GA) analysed general circulation model outputs from a total of 11 different Global Climate Models (GCMs), from two successive generations of GCM experiments referred to as CMIP3 and CMIP5. The models in the two frameworks are forced by different emission scenarios: the A2 scenario[1] for CMIP3 models and the RCP 8.5 scenario[2] for CMIP5 models. Both A2 and RCP 8.5 represent high emission scenarios.

Results from the latest generation CMIP5 models, for which no dynamical downscaling was required, indicate that these models tend to perform better at replicating the behaviour of tropical cyclones in the current climate, especially for the Southern Hemisphere. Thus, more confidence should be placed in the results from the CMIP5 framework. The results outlined in the following sections are based on the CMIP5 models.

The Mean Estimate reflects results obtained after averaging output over all five models under the same climate framework. Figure 2 displays the relative frequencies for different storm categories, for both current and Mean Estimate future climates.

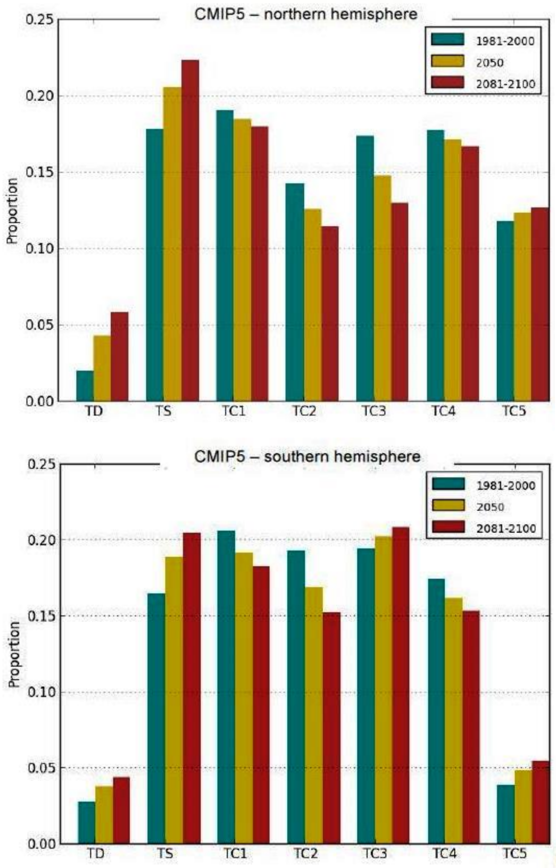


Figure 2: Mean Estimate relative proportion of TC intensity – multi model ensemble for CMIP5 models in the Northern and Southern Hemispheres. Classification is based on central pressure using Cp-based Saffir-Simpson Hurricane Intensity Scale

For both hemispheres, there is an expected future increase in the relative frequency of tropical depressions, tropical storms, and category 5 storms and a general decrease in the number of storms in the other categories. Most notable is the increase in category 5 storms (and category 3 storms in the southern hemisphere) which may have a measurable impact on observed losses in the region. There is also a slight equatorward movement of tropical cyclone tracks in the northern hemisphere and poleward movement of tropical cyclone tracks in the southern hemisphere.

Future loss projections

Of the five individual models analysed, generally three models suggest large increases in losses and two

[1] http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=98
[2] http://link.springer.com/content/pdf/10.1007%2Fs10584-011-0148-z.pdf

suggest decreases in losses. The significant divergence in the individual model results indicates a large range of model estimates. Figure 3 shows end-of-century individual model projection for Exceedance Probability (EP – see Appendix) (blue) along with the current climate EP (green).

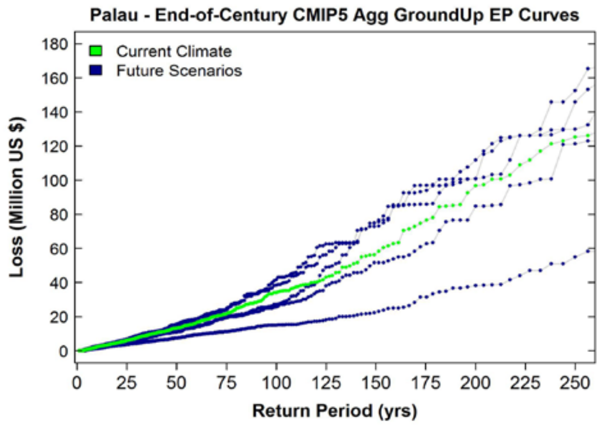


Figure 3: End-of-century EP-curves for individual CMIP5 models compared to the current climate EP-curve (green curve)

Any analysis of future model projections should consider estimates of the ensemble mean (the 'Mean Estimate' of all models), the full range of model results, and the worst case climate change scenario. The individual model that projects the greatest increase in losses as compared to the current climate defines the worst case scenario for the country. There are both increases and decreases in future losses from tropical cyclones, across different return periods. Figure 4 contrasts the end-of-century Mean Estimate projection with the current climate.

The two EP-curves tend to keep in close proximity, intersecting at around the 175 year return period, indicating increases in future loss beyond this point. Lower frequency events (higher return periods) are projected to cause larger increases in losses in the future climate.

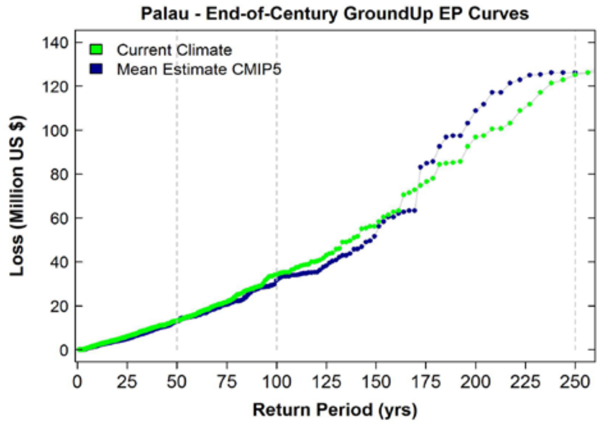


Figure 4: End-of-century EP-curve for the future Mean Estimate (blue curve) compared to the current climate EP-curve (green curve)

Mean Estimate projections indicate that, by end-of-century, losses from a 250-year return period event will increase by 0.8% compared to the current climate, while the worst case scenario (most upper curve in Figure 3) suggests a much more significant increase in loss of 21.9%.

Table 2: Loss estimates (USD) for current climate and future end-of-century Mean Estimate and worst case scenario

CMIP5 (Total Loss)	AAL	50yr RP	100yr RP	250yr RP
Current Climate	2,344,594	13,153,178	34,081,279	125,168,907
Future Mean Estimate	2,095,494	12,824,628	31,557,662	126,131,980
Future Worst Case	2,391,782	11,017,779	27,028,687	152,562,362

Table 2 contrasts current climate losses with the future Mean Estimate and worst case climate change scenario estimate across different return periods. The worst case scenario consistently projects loss increases when compared to the current climate across higher return periods considered as well as the AAL.

Mid-century v end-of-century future loss projections by different assets

Projected future losses from tropical cyclones were examined for mid-century and end-of-century across different assets (buildings, infrastructure, crops and population). There is a general decrease in losses from tropical cyclones in Palau by end-of-century. The AAL increases from 2.34 million USD to 2.35 million USD by mid-century and decreases to 2.1 million

USD by the end-of-century, for an end-of-century decrease of -10.6%, respectively.

Table 3 contrasts the AAL and the 50, 100 and 250 year RP losses from current and future climates, for both 2050 and 2100 time periods, across the different assets at risk. The total loss (AAL) represents the sum of the building, infrastructure and crop AALs.

All assets exhibit comparable mixed sign changes in loss, across different return periods. In general, the end-of-century losses decrease for small to medium return periods and increase for high return periods (> 175-year RP). Fewer people tend to be affected (in terms of casualties and fatalities) by the end-of-century tropical cyclone risk compared to the current climate.

Note that no adjustment to account for future economic or population growth was considered for any of the assets.

Table 3: Percent changes between future climate loss projections for mid-century and end-of-century and the baseline, for different return periods, by different assets. Baseline loss numbers are expressed in USD

Mean Estimate		AAL	50yr RP	100yr RP	250yr RP
Total Loss	Current Climate	2,344,594	13,153,178	34,081,279	125,168,907
	Future 2050 (%)	+0.3	-17.0	-26.5	-1.8
	Future 2100 (%)	-10.6	-2.5	-7.4	+0.8
Building	Current Climate	2,098,419	11,827,100	31,848,415	121,152,220
	Future 2050 (%)	+1.0	-19.4	-26.2	-1.8
	Future 2100 (%)	-10.6	-1.9	-6.7	+0.7
Infra-structure	Current Climate	56,129	328,612	861,522	3,014,713
	Future 2050 (%)	+5.5	-20.2	-20.4	+4.3
	Future 2100 (%)	-11.1	+1.1	-2.6	+4.3
Crop	Current Climate	190,046	1,253,866	1,468,083	1,669,634
	Future 2050 (%)	-8.6	-7.0	-5.6	-5.2
	Future 2100 (%)	-11.2	-8.5	-6.2	-3.9
Population Affected	Current Climate	3	28	61	135
	Future 2050 (%)	-10.1	-17.9	-21.3	-0.7
	Future 2100 (%)	-8.1	-3.6	-6.6	+0.0

It is uncertain why the tropical cyclone risk for Palau is projected to increase slightly in 2050 compared to a decrease in 2100, for the AAL. A hypothetical explanation could be related to the different changes in latitude imposed under the two climate projections; this could result in a different number of storms of different intensities impacting the country at the two time periods. Further investigation will be necessary to fully understand this finding.

Wind, flood and surge contributions to total loss estimates

The analysis captures the effects of three hazards associated with tropical cyclones: strong winds, precipitation-induced flooding and coastal flooding due to storm surge. Tropical cyclone winds can be very destructive and in most cases they are the main cause of damage and subsequent losses.

Unlike the wind, which decreases in intensity as the storm moves inland, the intensity of storm-related precipitation and accumulated runoff can increase in inland regions and consequently also lead to significant damage to property.

The storm surge represents the sea water forced ashore due to the rise in sea level accompanying any approaching intense storm. A significant storm surge event can have devastating effects on-shore.

Both sea level and precipitation changes under future climates are not considered in this study.

The main contributor to building and infrastructure loss is wind, with only minor contributions from storm surge and flood. Figure 5 explores the *relative changes* in contributions to total loss split by hazard between the current and the Mean Estimate future climate.

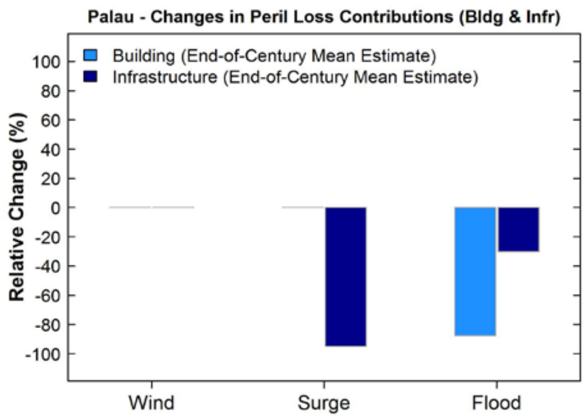


Figure 5: Percent changes between the end-of-century future climate and the current climate for Wind, Surge and Flood loss contributions to total loss, for buildings (light blue) and infrastructure (dark blue)

The flood contribution to total loss decreases for both buildings and infrastructure compared to the current climate. The infrastructure storm surge contribution also decreases. However, it is important to note that the reported changes for storm surge and flood are calculated between very small initial numbers and, ultimately, wind remains the main contributor to total loss for both assets.

Wind hazard maps for end-of-century climate compared to current climate

The wind hazard decreases slightly for the 100 year return period under future climate, as shown in Figure 6. The 100-year return period winds, which represent an event that has a 40% chance of being equalled or exceeded once in 50 years, are capable of generating severe damage to buildings, infrastructure, and crops with consequent large economic losses.

Figure 6 depicts the end-of-century 100 year mean RP wind speed, expressed as maximum 1-minute sustained winds in km/h, for the current climate (top panel) and future projection (bottom panel). For example, for Koror, the 100 year RP wind speed decreases from 155.3 km/hr to 151.6 km/hr by the end of century.

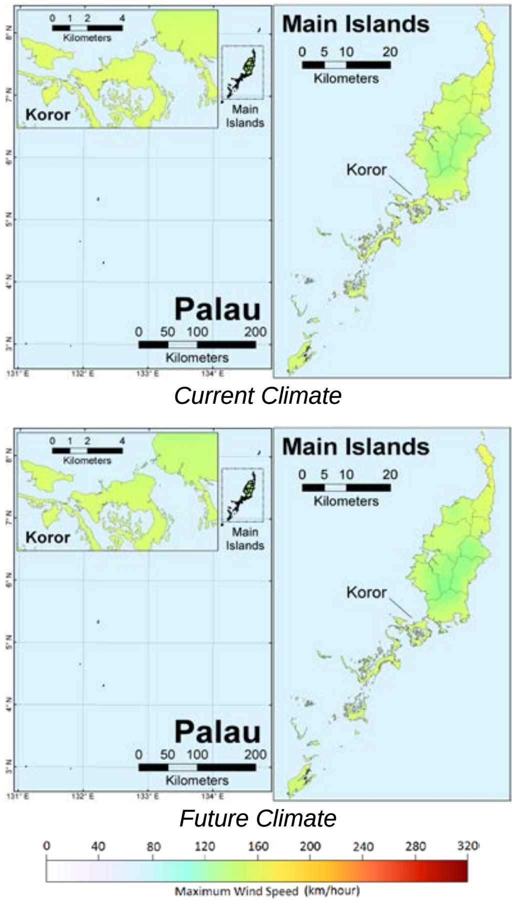


Figure 6: 100 year mean return period winds (maximum 1-minute sustained winds in km/h) for the current climate (top panel) and the future climate (bottom panel)

The wind level changes are less dramatic than the changes in total losses, because a small change in wind speed can result in significantly larger damage costs.

The current climate wind patterns in Palau are generally maintained across the islands under future projections.

SUMMARY

The evaluation of the current and future climate tropical cyclone risk in the South Pacific region was carried out using Geoscience Australia's analysis of tropical cyclone activity along with AIR's catastrophe model developed specifically for the region. The risk model allows for the translation of the climate change induced effects observed in the frequency, intensity and path of tropical cyclones into direct loss results for the region and individual countries.

For both hemispheres, numerical models predict a future increase in the relative frequency of tropical depressions, tropical storms, and category 5 storms and a decrease in the number of storms in other categories (Figure 2). Most notable is the regional increase in category 5 storms.

The financial impacts are measured using metrics such as the Average Annual Loss (AAL) or the 100 year return period loss. For planning purposes, it is useful to understand both average annual losses as well as possible losses from extreme events.

The Mean Estimate (Table 3) displays both increases and decreases in losses at various return periods compared to the baseline. Larger increases in losses are projected for lower frequency events (> 175-year RP - Figure 4).

For extreme events (250-year RP) the end-of-century Mean Estimate suggests an increase in loss of 0.8% compared to the current climate, while the worst case scenario suggests a significant increase in loss of 21.9% (Table 2).

All assets exhibit comparable mixed sign changes in loss (Table 3), with end-of-century increases for more extreme events (except for crop). In general, a lower proportion of the population tends to be affected by future tropical cyclone risk compared to the current climate.

The main contributor to total losses to buildings and infrastructure is wind, with only minor contributions from storm surge and flood. There are decreases in the flood and surge contributions to total loss (Figure 5) for the future climate. Similar to the current climate, the wind hazard remains the main contributor to loss for both assets. The end-of-century Mean Estimate projects slightly smaller winds compared to the current climate (Figure 6). The current climate general wind hazard patterns are maintained across the country.

Models from both the CMIP3 and CMIP5 global climate model runs were analysed in this project. The CMIP5 models demonstrated greater skill in replicating current climate conditions, and reporting of damage and loss has therefore focused on results from the CMIP5 framework.

There is consistent divergence, in the resulting EP-curves for individual models under the same framework (Figure 3) indicative of significant model uncertainty. The mean changes in future losses compared to the baseline are too small to be considered statistically significant when measured against the range of model estimates.

There is also the uncertainty associated with the risk model itself that needs to be accounted for. A statistical quantification of the uncertainty around each estimated EP-curve reveals that the separation between the baseline and the future projection is not large enough to be considered statistically significant.

APPENDIX

Classification of tropical cyclones

A tropical cyclone represents an atmospheric low-pressure system with a spiral arrangement of thunderstorms that produce strong winds and heavy rain. The table below describes the categorisation of storms based on maximum sustained winds and minimum central pressure as used in this study.

Classification	1-minute sustained wind speed (km/h)	Minimum central pressure (hPa)
Tropical Depression (TD)	<= 62	>= 1005
Tropical storm (TS)	63-118	1005-995
Category 1 (TC1)	119-153	995-980
Category 2 (TC2)	154-177	980-965
Category 3 (TC3)	178-208	965-945
Category 4 (TC4)	209-251	945-920
Category 5 (TC5)	>= 252	< 920

Definition of key metrics used to describe future risk changes

Several key metrics are utilised in order to evaluate the change in losses/risk between the current climate and the future climate: Average Annual Loss (AAL), Return Period (RP) Loss, Exceedance Probability (EP) curve.

- Average Annual Loss (AAL). AAL represents the sum of all losses observed in the domain divided by all realisations of next-year activity (10,000 years); AAL thus refers to the average loss that can be expected to occur per year.
- Return period (RP) loss. The X-year return period loss is the loss that can be expected to occur or be exceeded on average once every X years. Highlighted for this analysis are the 50 year (2.0% exceedance probability), 100 year (1.0% exceedance probability) and 250 year (0.4% exceedance probability).
- Exceedance Probability curve (EP-curve). An EP-curve represents the probability curve that various levels of loss will be exceeded. By inverting the exceedance probability to obtain corresponding return periods, the EP-curve then represents the various levels of loss associated with different return period events. An EP-curve is obtained by sorting all losses largest to smallest observed over a domain, assigning a rank to all entries (1 being the largest loss, 2 being the second largest loss etc.), and then dividing the ranking by the total number of years (10,000).

Loss and damage

The 'losses' referred to in this report represent the 'damages'; (i.e., the direct ground up-losses before the application of insurance (zero deductible)), plus an estimation of the emergency losses (i.e., debris removal, setting up shelters for those made homeless, or supplying medicine and food). All estimates of current and future losses in this report are in 2010 dollars.

Australian Government

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AIR WORLDWIDE

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